The Origin of Fahrenheit's Thermometric Scale

By Dr. J. Newton Friend

THE scientific world has recently paid tribute to the bicentenary of the death of the renowned German instrument maker, Daniel Gabriel Fahrenheit[1], who was born in Danzig in 1686 and died at The Hague on September 16, 1736.

Ever since the general acceptance of his thermometric scale, there has been much discussion as to why Fahrenheit chose such an apparently inconvenient numerical relationship as 32° and 212° for the freezing and boiling points of water respectively. Published opinions have differed widely. Martine, a contemporary of Fahrenheit, believed that, having once fixed his zero, Fahrenheit chose his scale in a purely haphazard manner, as explained later on. On the other hand, an entirely different view is put forward in Chambers' "Encyclopædia"[2], where we read :

"Fahrenheit took as his zero the lowest temperature then obtainable (from a mixture of salt and ice) and called the temperature of the human body 8°. Each degree was subdivided into 12 parts ; and subsequently these twelfths were taken as degrees. This made the temperature of the body 96° ; and it was found that the freezing point of water was 32°."

These illustrations will suffice.

Fresh light has been thrown on the problem by the recent discovery in the Military Medical Academy at Leningrad of certain letters sent by Fahrenheit to Boerhaave during the period 1718–29. These letters were written in Dutch at Amsterdam, and a literal translation of one of them into German, dated April 17, 1729, is given by the Cohens (*loc. cit.*)[1], which enables us to settle the question fairly satisfactorily.

It may be said at once that Fahrenheit did not choose 32° and 212° for the freezing and boiling points of water ; they were mere incidents on his scale, which was chosen independently of them and was based upon two fixed points, namely, a zero obtained by immersing his thermometer in a mixture of ice and sal ammoniac, and an upper point at blood heat, which Fahrenheit took as 96°.

The purpose of the present article is to attempt to explain :

(i) Why the above mentioned temperatures were chosen as bases of Fahrenheit's scale in preference to the freezing and boiling points of water ; and

(ii) why the upper fixed point was designated as 96°.

In order to answer these questions a knowledge of the early history of thermometry is necessary. A brief résumé is all that can be attempted in these columns.

The term thermometer appears to have been first used by Father Leurechon (1591–1670), a French Jesuit, in his work entitled "Récréation Mathematique", dated 1624. The credit of inventing thermometers with a liquid indicator (actually spirits of wine) hermetically sealed in a glass tube is usually given to Ferdinand II (1610–70), about 1650 ; he was Grand Duke of Tuscany, a liberal patron of science and founder of the Accademia del Cimento at Florence. Prior to these, air thermoscopes or baro-thermoscopes had been used for comparing relative changes in temperature. These were (probably) invented either by Santorio (1561–1656), professor of medicine at Padua and colleague of Galileo, or by Galileo (1564–1642) himself, about 1592. The utility of these thermoscopes was severely limited by their susceptibility to changes in atmospheric pressure. As no standard temperature scale was recognized, it was at first impossible, even with the Ferdinand or Florentine thermometers, to collate the results of different investigators. This very serious defect was soon realized, and steps were taken to find a remedy.

The Liquid Indicator

It was regarded by some as sufficient to select a single fixed point at an easily reproducible temperature and regard that as the zero or null point. Other temperatures were measured by noting the percentage or other fractional change in volume of the liquid indicator once the null point had been marked off on the thermometer.

Clearly the nature of the liquid medium was a matter of supreme importance, for, if the results of different investigators were to be collated, either the same liquid indicator must be used by all, or one possessed of an identical coefficient of expansion. Halley (1656–1742) directed attention to this, having observed that all liquids do not expand by similar amounts with rise of temperature[3]. Further, the exact volume of the liquid in the bulb of the thermometer must be known in order that the fractional volume change may be calculated and the temperature evaluated.

Boyle (1627–91) proposed *water*. He recommended taking a vessel of water and noting the volume of the liquid at the boiling point. On cooling to a lower temperature, the latter could be registered in terms of the contraction of the water as parts per 10,000 of the boiling volume. But this suggestion did not find favour despite the abundance of water and the ease with which it could be obtained in a pure condition. Water was regarded as an unsuitable liquid indicator, for not only was its coefficient of expansion small as Halley pointed out[4], but also its freezing point was too high for many meteorological purposes, and it was for this kind of work that thermometers were largely required. Its irregularity of expansion with rise of temperature did not much matter; it would scarcely be noticed, for the general experimental error was high.

Newton[5] (1642–1727) used *linseed oil*, noting its volume at the temperature of melting ice and, like Boyle, expressing its change in volume as parts per 10,000. Martine[6] quaintly refers to his experiments as follows:

> "Sir Isaac Newton thought the settling [of] the degrees of heat and cold well worth his notice; and as he carried everything he meddled [*sic*] with beyond what anybody had done before him, and generally with a greater than ordinary exactness and precision, so he laid down a method of adjusting thermometers in a more definite way than had been done hitherto."

But although linseed oil has a low freezing point and a large range of liquidity, its use in thermometry did not become general, despite Newton's fame as an investigator and the fact that the oil could be used at temperatures far above the boiling point of water. This was probably due to the fact, to which Martine directs attention, that, in consequence of its high viscosity, the oil drains very slowly, particularly at the lower temperatures, down the sides of the tube bearing the scale; the thermometer thus takes a long time to adjust itself to new conditions.

Ferdinand (*vide supra*) ordered his thermometers to be made with *spirit*; Boyle was quick to appreciate their merits and introduced them into England. Referring to them, Martine says they "came immediately to be of universal use among the virtuosi in all the several countries, wherever polite learning and philosophy were cultivated". The scale divisions were approximately one fiftieth of the volume of the bulb. Sagredo[7] used 360 divisions, like the graduation of a circle; hence the term degree, as applied to temperature.

The low freezing point and viscosity of spirit were excellent features, but a really serious difficulty lay in the fact that the coefficient of expansion was found to vary greatly with the quantity of admixed water. Réaumur, as we shall presently see, made use of this property when devising his scale some years later.

Fahrenheit favoured the use of *mercury* as well as of spirit; indeed he was the first to bring the mercurial thermometer into general use.

Martine, as has already been mentioned, believed that Fahrenheit chose his scale in a purely haphazard manner, using mercury as indicator. He records that Fahrenheit took a volume of mercury measuring 11,124 parts when cooled in ice and sal ammoniac; 11,156 parts in melting ice—a rise of 32 parts or degrees; and 11,336 parts in boiling water—a rise of 212 degrees *in toto*; whence his scale. Martine[8] then comments on the extremely arbitrary character of the scale, adding, "I confess there might have been a more convenient one fixed upon at first". We agree.

Martine quotes as his authority Hermann Boerhaave (1686–1738), professor of medicine and chemistry at Leyden, from whose work entitled "Elementa Chemiae"[9] the above accounts were taken. There is evidently a misunderstanding here for, in view of Fahrenheit's letter to Boerhaave discussed below, it does not seem at all possible that this could have been the origin of his scale. It is more probable that, if Fahrenheit did carry out this experiment, the particular volume of mercury was deliberately chosen because it would give the necessary expansion to fit in with his own already existing scale.

SELECTION OF FIXED POINTS

Some investigators, Martine included, advocated the use of a thermometric scale based upon two fixed points instead of one only. Any suitable liquid could then be used as indicator, and the necessity no longer existed for determining with great accuracy the volume of the bulb of the thermometer. All that one had to do, and this was comparatively easy, was to note the levels at the two fixed points and divide the distance between them into as many parts or degrees as was held convenient. Newton and Ole Rœmer (see below) appear to have been the first to devise such scales prior to 1703.

Numerous suggestions were made for the selection of fixed points. Boyle[10] recommended the freezing point of oil of aniseed (17°–20° C.) as zero, because it was not necessary to wait for frosty weather before it solidified. Halley thought a cave might be selected where summer and winter temperatures are alike; one such cave was known to Boyle, and Mariotte[11] claimed that the cave under the Royal Observatory at Paris was also isothermal. Newton chose the freezing point of water as his zero.

Boyle[12] was aware that an intense cold could be produced by mixing ice and salt. Ole Rœmer (1644–1710), the Danish astronomer famous for his measurement of the velocity of light from a study of the movements of Jupiter's satellites, used this mixture or a similar one (ice and sal ammoniac, see later) in obtaining his zero, which was regarded as the lowest temperature then attainable in the laboratory. Some years later, Fahrenheit adopted the same zero, and has hitherto, but incorrectly, been regarded as its originator.

Boyle's suggestion is ruled out because oil of aniseed is a natural product and as such does not possess a fixed composition; its melting point is thus liable to vary. For geographical reasons, Halley's idea is impracticable, as a particular cave could not be visited by everyone desirous of checking his thermometer.

Newton's idea appears to be the simplest and most convenient. Why, then, was it not generally adopted?

The reason seems to be that scientific investigators believed the freezing point of water was not constant, but varied with the latitude, Halley and others asserting that, the farther north we go, the more cold is required to freeze the water—to use the then current phraseology.

Martine[13] refers to this, and appears to have been the first to show that such is not the case. He rightly attributes the observed differences in the freezing point of water either to inaccurate observation or to the use of imperfect thermometers. He says that he marked the mercury level on a thermometer at Edinburgh, when immersed in snow and water, whilst a friend did the same with another thermometer in London. They then exchanged instruments and tested them, finding them to agree perfectly. Evidently the difference in latitude between the two cities had not affected the freezing point. Later experiments as far south as Paris and Dijon yielded similar results.

For his upper fixed point Newton chose blood heat; this was regarded as absolutely constant for a healthy person. He designated this temperature as 12°, probably because the number is easily subdivided and remembered, as there are 12 inches to the foot; the decimal system was not in general use in scientific work. As we have seen, his 0° was obtained in melting ice.

In "Adversaria", which was printed in 1910, the MS. having been mislaid for about 200 years[14], Rœmer gives an account of the construction by him of a standard thermometer in 1702–3. The scale of this thermometer was based upon *two* fixed points, the upper one being the boiling point of water, which he designated as 60. In checking his thermometers he used this temperature and, for convenience, possibly also for greater accuracy, the melting point of snow or crushed ice. This latter temperature, however, was not his zero, but fell on his scale at 7½ degrees. According to Fahrenheit, Rœmer also used blood heat in checking his thermometers, presumably when intended for meteorological use, as it was not necessary for these to be graduated to so high a temperature as the boiling point of water. In his letter to Boerhaave dated 1729, to which reference has already been made, Fahrenheit states that he met Rœmer in Copenhagen in 1708 and saw him testing some thermometers by placing them first in ice and water and afterwards into water at blood heat. The scales on the instruments were divided into 22½ parts, beginning at 0. When placed in iced water the reading was 7½; at blood heat, 22½. How the zero was obtained is not definitely stated either in "Adversaria" or in Fahrenheit's letter, but simple calculation shows that it corresponds roughly to the temperature of a mixture of salt and ice. This is supported by the fact that Fahrenheit then goes on to say that he himself later adopted the same temperature scale but with this small difference, namely, that he divided each of Rœmer's divisions into quarters, presumably for ease of reading. Evidently, therefore, Fahrenheit adopted the same zero, and this, he had stated[15] in 1724, was obtained "by the commixture of ice, water and sal ammoniac, or even sea salt". From the fact that he quotes sal ammoniac and sea salt as alternatives we gather that Fahrenheit supposed they yielded the same temperature with ice. We now know that their cryohydric points are $-15°$ C. (or $+5°$ F.) and $-22°$ C. (or $-8°$ F.) respectively. Nevertheless, Fahrenheit did realize that there was a difficulty in reaching the true zero, for he naïvely remarks that "if into this mixture the thermometer be put, it descends to 0. This experiment succeeds better in winter than in summer"!

We wonder what the toleration of his thermometers would amount to. Martine mentions[16] that he had occasion to test some Dutch mercurial thermometers, but found them in error by one or two degrees.

Halley[17] recommended, for the upper fixed point, the boiling point of spirit of wine,

> "only it must be observed, that the spirit of wine used to this purpose, be highly Rectified or Dephlegmed for otherwise the differing goodness of the spirit will occasion it to boil sooner or later, and thereby pervert the designed exactness".

Several workers recommended the boiling point of water as the upper fixed point, using the freezing point as zero. Martine favoured this idea and it was acted upon by René de Réaumur (1683–1757), the French scientist, who found that the best spirits of wine of his day expanded by 87½ parts per 1,000 when warmed from melting ice to boiling water[18]. Equal parts of his spirit and water gave an expansion of 67½. He therefore for simplicity chose such a mixture as expanded by

80 parts. Hence the Réaumur scale runs from 0° to 80° between those two temperatures. The choice was not accidental, as we frequently read, but by design.

In 1736 Celsius (1701–44), in contrast to previous workers, favoured the decimal system and divided the same interval into 100, thus giving us the Centigrade thermometer. At first he denoted the freezing point by 100 and the boiling point by 0, but this scale was afterwards inverted.

It was known to Martine[19], to Fahrenheit and possibly also to Boyle that the boiling point of water varies with the pressure. This, however, was not regarded as a serious drawback to its use as a fixed point because, as Martine states,

"in ordinary changes of the weather, the difference is not very great. And farther, we may avoid all errors that might arise from anything of that sort, if we make our observations on the heat of boiling water, and adjust this term of heat at a middle state of the atmosphere in places near the level of the sea, when the quicksilver in the barometer stands at about 30 inches, or a very little under it. And the same caution will be necessary in judging the heat of boiling spirit of wine, or of the boiling heat of any other liquid."

The Fahrenheit Scale

We have seen that Fahrenheit, on his own admission, based his scale on that of Rœmer. This confirms the conclusion to which Kirstine Meyer[14] had already come in 1910, after examining the scales on some early Fahrenheit thermometers and collating various statements in contemporary literature.

If we ask what were the features of Rœmer's scale that attracted him and led him to reject the freezing and boiling points of water as his zero and upper fixed point respectively, the answer is undoubtedly to be found in the fact that the majority of his thermometers were intended for meteorological purposes.

The freezing point of water is relatively high, and if taken as zero involves the repeated use of negative values for winter temperatures. By using the then lowest attainable temperature as zero—the "absolute zero" of those days—all the meteorological readings would be positive. Fahrenheit probably objected to the conception of a negative temperature, just as we do to-day in regard to our own absolute scale.

As regards the upper fixed point, the temperature of boiling water was rejected as being unnecessarily high for meteorological purposes and inconveniently high for spirit thermometers. Fahrenheit states[20] that he was accustomed to use the same fixed points for all his instruments, whether spirit or mercury, when intended for meteorological purposes.

Fahrenheit went on to say, in his letter to Boerhaave, that in 1717 he felt Rœmer's scale with its fractions to be both inconvenient and inelegant; so instead of $22\frac{1}{2}°$ divided into quarters, that is, 90, he decided to take 96° as blood heat. Retaining the same zero, the melting point of ice became 32°, instead of $7\frac{1}{2}°$ divided into quarters, or 30. This scale he continued to use and was using at the time the letter was written (that is, in 1729); he added that he had been confirmed in his choice because he found it to agree, by pure coincidence, with the scale marked on the thermometer hanging in the Paris Observatory.

Fahrenheit gave no reason for regarding the number 96 as more convenient than 90. Probably it was due to the fact that 96 is divisible not merely by 3 but also by multiples of 2 and hence by 12. The decimal system was not then in general use in scientific work, otherwise Fahrenheit would no doubt have fixed blood heat at 100°. In that case the freezing and boiling points of water would have been represented by numbers even more awkward and disconnected, namely, 33·3° and 221° respectively. So let us be thankful.

Although we retain a Fahrenheit scale to-day, it is not quite the same as that which Fahrenheit used. The lower and upper fixed points adopted are those deliberately rejected by Fahrenheit, ice being taken to melt at 32° and water to boil under standard conditions at 212°.

In conclusion, I gladly express my indebtedness to Mr. H. W. Robinson, librarian of the Royal Society, to the staff of the Birmingham Public Library and last, but by no means least, to my friend Mr. F. W. Clifford, librarian of the Chemical Society, for their kind assistance whilst I have been examining the early documents referred to in this article.

[1] See Cohen, E., and Cohen-De Meester, W. A. T., *Kon. Akad. Wet. Verhand.* (Eerste Sectie), **16**, No. 2, pp. 1–37. Amsterdam, 1936. See NATURE, **138**, 428 (1936).

[2] New Edition, by Patrick and Geddie, **10** (1927), under "Thermometer". A similar view is put forward by Higgins, *J. Roy. Soc. Arts*, **74**, 946 (1926).

[3] Halley, *Phil. Trans.*, Lowthorp's Abridged Edn., **2**, 33.

[4] Halley, *loc. cit.*, **2**, 34.

[5] Newton, *Phil. Trans.*, 824 (1701). The paper, which is anonymous, is entitled "Scala graduum Caloris", and appears in Latin. See also Brewster, "Life of Sir Isaac Newton", **2**, 362–8 (1855).

[6] Martine, "Essays on the Construction and Graduation of Thermometers". (New edition, Edinburgh, 1792.) The first essay, from which these and succeeding quotations are taken, is dated 1738.

[7] Sagredo. See "The Times Century Dictionary" under "Thermometer".

[8] Martine, *loc. cit.*, p. 30.

[9] Two volumes, dated 1732. See **1**, 174, also 162–165.

[10] Boyle, "An Experimental History of Cold", 39 (1665).

[11] *Phil. Trans.*, Lowthorp's Abridged Edn., **2**, 36.

[12] Boyle, *loc. cit.*, 156.

[13] Martine, *loc. cit.*, p. 15.

[14] See Kirstine Meyer, NATURE, **82**, 296 (1910); also "Adversaria" by Thyra and K. Meyer (København, 1910), reviewed NATURE, **86**, 4 (1911).

[15] Fahrenheit, *Phil. Trans.*, **33**, 78 (1724). Printed in Latin. This quotation is from *Phil. Trans.*, Hutton's Abridged Edn., **7**, 22–24.

[16] Martine, *loc. cit.*

[17] *Phil. Trans.*, Lowthorp's Abridged Edn., **2**, 35.

[18] Réaumur, *Mem. Acad. Roy.*, 452 (1730).

[19] Martine, *loc. cit.*, 10.

[20] Fahrenheit, *Phil. Trans.*, **33**, 78 (1724).